

## List of Nomenclature

Symbol	Description	Unit
$\delta$	Skin depth or penetration depth.	[mm]
$\mu$	Magnetic permeability.	[H/m]
$\mu_r$	Relative magnetic permeability.	[H/m]
$\mu_0$	Permeability of free space.	[H/m]
$\rho$	Electrical resistivity.	[ $\Omega$ .m]
$f$	Applied frequency at the work-piece.	[Hz]
$J$	Current density.	[A/m]
$\sigma$	Electrical conductivity.	[S/m]
$\alpha$	Temperature coefficient for the material.	[-]
$I_s$	Surface current.	[A]
$c$	Specific heat	[J/Kg.K]
$I_x$	Current at distance $x$	[A]
$T$	Temperature	[ $^{\circ}$ c]
$T_{ph}$	phase difference time	[s]
$T_{on}$	Turn on time of PDM	[s]
$T_{off}$	Turn off time of PDM	[s]
$f_{clk}$	pulses with high frequency	[Hz]
$Q_{th}$	Thermal energy	[kW/hr]
$M$	Mass of the work piece	[Kg]
$\eta_{el}$	Electrical efficiency	[-]
$\eta_{th}$	Thermal efficiency	[-]
$A_g$	The air gap cross section area	[m <sup>2</sup> ]
$A_w$	The work-piece cross section area	[m <sup>2</sup> ]
$D_c$	The diameter of the work piece	[m]
$l_c$	The work-coil length	[m]
$Z$	Load impedance	[ $\Omega$ ]
$R_w$	Work-piece resistance	[ $\Omega$ ]
$R_c$	Work-coil resistance	[ $\Omega$ ]

$X_w$	Work-piece reactance	[ $\Omega$ ]
$X_c$	Work-coil reactance	[ $\Omega$ ]
$X_g$	Gap reactance.	[ $\Omega$ ]
$X_L$	Load inductive reactance.	[ $\Omega$ ]
$X_c$	Load capacitive reactance.	[ $\Omega$ ]
$R_p$	Equivalent resistance for parallel resonance.	[ $\Omega$ ]
$X_P$	Equivalent reactance for parallel resonance.	[ $\Omega$ ]
$R_L$	Load equivalent resistance.	[ $\Omega$ ]
$\delta_c$	Coil current penetration depth.	[mm]
$f_r$	Resonant frequency.	[Hz]
$L_p$	Load inductance	[H]
$C_t$	Tank circuit capacitance	[F]
$Q_p$	Parallel resonance quality factor.	[-]
$f_c$	Critical frequency.	[Hz]
$v_{inv}$	Inverter voltage	[V]
$i_{inv}$	Inverter current	[A]
$M$	Modulation index.	[-]
$D$	Pulse density.	[-]
$\tau$	Time constant.	[s]
$f_s$	Switching frequency	[Hz]
$L_f$	Filter inductance	[H]
$C_f$	Filter capacitance	[F]
$L_c$	Critical filter inductance	[H]
$f_i$	input source frequency	[Hz]
$\theta_{ref}$	Reference phase angle	[Deg.]
$\theta_{act}$	Actual phase angle	[Deg.]
$P_{ref}$	Reference (desired) system power	[kW]
$P_{act}$	Actual system power	[kw]
$L_c$	Series commutating inductor	[H]
$C_c$	Series commutating capacitor	[F]
$C_s$	Snubber capacitor	[F]
$R_s$	Snubber resistance	[ $\Omega$ ]

## List of Abbreviations

PDM	Pulse Density Modulation
PSC	Phase Shift Control
PWM	Pulse Width Modulation
AFC	Automatic Frequency Control
PFM	Pulse Frequency Modulation
DCC	Duty Cycle Control
PLL	Phase Locked Loop
DCM	Discontinuous Conduction Mode
AVC	Automatic Voltage Cancellation
FV	Frequency Variation
VCO	Voltage Controlled Oscillator
PFB	Power Feedback
PD	Phase Detector
CSI	Current Source Inverter
RMS	Root Mean Square
DC	Direct Current
AC	Alternating Current
GTO	Gate Turn Off Thyristor
PRC	Parallel Resonant Converter
SRC	Series Resonant Converter
ZVS	Zero Voltage Switching
ZCS	Zero Current Switching
IGBT	Insulated Gate Bipolar Transistor
SCR	Silicon Controlled Rectifier
BJT	Bipolar Junction Transistor
THD	Total Harmonic Distortion
EMF	Electromagnetic Force
EMI	Electro Magnetic Interference
ROM	Read Only Memory
PI	Proportional Integral

# List of Illustrations

## I. Figures

- Figure 1.1 Basic concepts of induction heating
- Figure 1.2 Induction heating applications
- Figure 1.3 Layout of basic induction heating system
- Figure 2.1 Proposed feedback and power circuit block diagram
- Figure 3.1 Faraday's Induction law
- Figure 3.2 Current distribution with depth
- Figure 3.3 Layout of the high frequency solid state power source
- Figure 3.4 Inverter power control (a) swept frequency, (b) Load resonant.
- Figure 3.5 Classifications of resonant-converter topologies
- Figure 3.6 Basic resonant converter configurations
- Figure 3.7 Series resonant converter topologies with bidirectional switches
- Figure 3.8 tank circuit electrical representation
- Figure 3.9 Resonance circuit frequency response
- Figure 3.10 (a) parallel resonance in induction heating, (b) equivalent representation
- Figure 3.11 PDM pattern cycle waveforms (gate pulses of inverter switches).
- Figure 3.12 Output current and voltage waveforms with PDM
- Figure 3.13 Operating modes in PDM (a) Main circuit, (b) Mode I, (c) Mode II, (d or e) Mode III.
- Figure 4.1 Schematic layout of proposed induction heating system
- Figure 4.2 Control circuit block diagram for PDM
- Figure 4.3 concept of phase detection
- Figure 4.4 Power feedback block diagram
- Figure 4.5 PDM pattern generation block diagram
- Figure 4.6 Pattern generation signals.
- Figure 4.7 Phase angle feedback sub-system
- Figure 4.8 Power feedback sub-system

- Figure 4.9 PDM control sub-system
- Figure 4.10 The closed loop control of PDM-based induction heating system
- Figure 4.11 (a) Inverter voltage in [V] and current in [A] for output power of 15kW (b) Zoom in for figure 4.11(a) at starting (c) Zoom in for figure 4.11(a) at steady state
- Figure 4.12 (a) IGBT voltage in [V] and current in [A] for output power of 15kW (b) Zoom in for figure 4.12(a) at starting (c) Zoom in for figure 4.12(a) at steady state
- Figure 4.13 Supply voltage in [V] and current in [A] for output power of 15kW
- Figure 4.14 IGBT voltage in [V] and current in [A] for output power of 10kW at steady state
- Figure 4.15 Inverter voltage in [V] and current in [A] for output power of (a) 10kW, (b) 1kW, (c) 0.2kW
- Figure 4.16 The actual power compared with the reference power for output power of (a) 10kW, (b) 1kW, (c) 0.2kW
- Figure 4.17 PDM pattern generation at reference power of 10 kW
- Figure 4.18 step response of the heating system, assuming different power levels
- Figure 4.19 Inverter current response for step change in the reference power
- Figure 4.20 Inverter voltage in [V] and current in [A] at different power levels

## II. Tables

Table 3.1 Relative properties of semiconductor devices

Table 4.1 System Parameters